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Modality exclusivity norms for 400 nouns: The relationship between perceptual experience and surface word form

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Abstract We present modality exclusivity norms for 400 randomly selected noun concepts, for which participants provided perceptual strength ratings across five sensory modalities (i.e., hearing, taste, touch, smell, and vision). A comparison with previous norms showed that noun concepts are more multimodal than adjective concepts, as nouns tend to subsume multiple adjectival property concepts (e.g., perceptual experience of the concept *baby* involves auditory, haptic, olfactory, and visual properties, and hence leads to multimodal perceptual strength). To show the value of these norms, we then used them to test a prediction of the sound symbolism hypothesis: Analysis revealed a systematic relationship between strength of perceptual experience in the referent concept and surface word form, such that distinctive perceptual experience tends to attract distinctive lexical labels. In other words, modality-specific norms of perceptual strength are useful for exploring not just the nature of grounded concepts, but also the nature of form–meaning relationships. These norms will be of benefit to those interested in the representational nature of concepts, the roles of perceptual information in word processing and in grounded cognition more generally, and the relationship between form and meaning in language development and evolution.

Keywords Perceptual modalities · Concepts · Nouns · Auditory · Gustatory · Haptic · Olfactory · Visual · Norms · Sound symbolism

Many contemporary views of conceptual representation hold that the perceptual system has been co-opted in the service of conceptual processing. That is, concepts are grounded in the same neural systems that are active in processing real-world perceptual, motor, and affective experience (Barsalou, 1999; Barsalou, Santos, Simmons, & Wilson, 2008; Glenberg, 1997; Lynott & Connell, 2010; Vigliocco, Meteyard, Andrews, & Kousta, 2009; cf. Mahon & Caramazza, 2008). Neuroimaging studies have found an overlap of cortical areas in perceptual and conceptual processing (e.g., Barrós-Loscertales et al., 2011; Goldberg, Perfetti, & Schneider, 2006; Newman, Klatzky, Lederman, & Just, 2005; Simmons et al., 2007; see also Hauk, Johnsrude, & Pulvermüller, 2004). Behaviorally, phenomena from the perceptual literature have also been found to emerge in conceptual processing. For example, switching attention between modality-specific systems incurs a processing cost for both pure perception (Spence, Nicholls, & Driver, 2001) and conceptual processing of perceptual properties (Pecher, Zeelenberg, & Barsalou, 2003; van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008). Furthermore, processing suffers a disadvantage in the tactile modality relative to other perceptual modalities, whereby people are slower and less accurate in detecting stimuli from touch sensation (Spence et al., 2001; Turatto, Galfano, Bridgeman, & Umiltà, 2004) and from words that relate to touch (Connell & Lynott, 2010). In short, these findings suggest

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that the conceptual "meanings" activated by words are inherently perceptual, because the conceptual and perceptual systems share representational and processing resources.

In previous work (Lynott & Connell, 2009), we collected modality exclusivity norms for adjectival object properties that asked people how strongly they experienced a particular concept by hearing, tasting, feeling through touch, smelling, and seeing. Each word is therefore associated with a five-value vector of perceptual strength in five modalities: auditory, gustatory, haptic, olfactory, or visual. These norms have been used in a variety of studies that have explored the perceptual grounding of conceptual representation, such as identifying the tactile disadvantage in word processing (Connell & Lynott, 2010), enhancing modality-switching costs in both property verification (Collins, Pecher, Zeelenberg, & Coulson, 2011; Hald, Marshall, Janssen, & Garnham, 2011; Lynott & Connell, 2009) and conceptual combination (Connell & Lynott, 2011), and modeling how statistical regularities in language reflect the perceptual content of concepts (Johns & Jones, 2012; Louwerse & Connell, 2011). However, these previous norms focused on adjective concepts (i.e., individual object properties such as *warm* or *loud*), which are necessarily different from noun concepts (i.e., objects and entities such as *blanket* or *sergeant*). Since noun concepts tend to comprise many adjective concepts (e.g., the same *blanket* can be *warm*, *itchy*, *blue*, *smelly*, etc.), each of which has its own individual, modality-specific profile, noun concepts are likely to encompass a broader range of modalities than do individual object properties and to have a greater potential wealth of perceptual information available for activation every time their labels are encountered.

Furthermore, the lexical attributes of such labels are not arbitrarily related to their meanings. A growing body of empirical research has suggested that sound symbolism in language extends beyond mere onomatopoeia into a variety of systematic form–meaning relationships (Farmer, Christiansen, & Monaghan, 2006; Imai, Kita, Nagumo, & Okada, 2008; Nygaard, Cook, & Namy, 2009; Perniss, Thompson, & Vigliocco, 2011; Thompson & Estes, 2011; cf. de Saussure, 1959). For example, round, curvy shapes are preferentially labeled with voiced consonants and back vowels (e.g., "bouba"), while pointed, angular shapes are contrastingly labeled with unvoiced consonants and front vowels (e.g., "kiki": Köhler, 1929; Ramachandran & Hubbard, 2001). Similar correspondences apply to modalities other than visual–haptic shape; people also consider the olfactory–gustatory flavor of mint chocolate to be more "kiki" (but less "maluma") than milk chocolate (Gallace, Boschin, & Spence, 2011). Such studies suggest that the perceptual information of a particular referent object is related to the surface qualities of its label. In other words, a strong test of the sound symbolism hypothesis would therefore expect the systematic relationship between word form and meaning to reflect the perceptual profile of the conceptual contents, which has not previously been examined.

In the present article, we present modality exclusivity norms for 400 noun concepts that contain ratings of perceptual strength in five modalities: auditory, gustatory, haptic, olfactory, and visual. We have used these noun norms, in combination with our earlier adjective norms, to show that measures of perceptual strength outperform both concreteness and imageability in predicting word-processing times and accuracy (Connell & Lynott, in press) and to establish the differential activation of semantic information by perceptual attention (Connell & Lynott, 2012). The noun norms represent a significant extension of both our previous adjectival property norms (Lynott & Connell, 2009) and a recent set of property–concept norms (van Dantzig, Cowell, Zeelenberg, & Pecher, 2011) for two reasons. First, our present norms do not try to restrict the perceptual profile of the concept to a particular property (e.g., haptic *warm*, visual *red*), but instead allow the full multimodal range of the concept to emerge. Second, the previous norms were deliberately geared toward concrete, highly perceptual properties because of their intended use, whereas our present norms represent a random selection of familiar nouns with no perceptual bias, and are therefore more representative of general language use. This representative sample of nouns, then, allows us to examine whether our ratings of perceptual strength in five modalities can predict the surface lexical characteristics of the words.

Noun modality norming

Method

Participants A group of 34 native speakers of English took part for course credit.

Materials The MRC psycholinguistic database (Coltheart, 1981; Wilson, 1988) was used to generate a random list of 400 nouns. Function words, relatively unfamiliar words (MRC familiarity scores less than 450 out of 700), and any words that featured in the previous adjective norms (e.g., *red* can be either an adjective or a noun; Lynott & Connell, 2009) were replaced.

Procedure The material set was randomly split into two lists of 200 items and presented to participants for perceptual strength ratings in a norming procedure based on that of Lynott and Connell (2009). Each word was presented on a separate screen (order randomized per participant) with a line that read "To what extent do you experience *WORD*" (with the *WORD* slot being filled with the noun in question).[1] Underneath this line were five separate rating scales for each perceptual modality, labeled "by feeling through touch," "by hearing," "by seeing," "by smelling," and "by tasting." The order of the modalities was fixed across items for each participant, but was counterbalanced across participants in a Latin square. Participants were instructed to rate the extent to which they would experience each concept through each of the five senses, from 0 (*not at all*) to 5 (*greatly*). The numerical rating scale was displayed with no default value selected, and participants clicked on a number (which circled the relevant value) to indicate, or change, their rating. After rating the concept on all five modalities, participants clicked on the "Next" button to advance to the subsequent item. Participants were told that there were no right or wrong answers and that they should use their own judgment; they were also told that, if they did not know the meaning of the word, they should skip it by immediately clicking "Next" to move on to the following item. The experiment was self-paced and lasted between 45 and 60 min.

Results and discussion

The participants' responses were collated, excluding skipped trials or scales (1.6% of the data), and mean ratings per modality were calculated for each noun, resulting in 2,000 unique data points. Table 1 shows the mean strength rating for each perceptual modality, along with measures of spread. The reliability for all modalities was high, as was shown by the Cronbach's alphas for interitem consistency (auditory = .977, gustatory = .942, haptic = .971, olfactory = .969, visual = .972). Participants also showed high interrater reliability for each modality, according to Cronbach's alphas for interrater agreement (auditory = .907, gustatory = .938, haptic = .924, olfactory = .922, visual = .875). Note that while lexical ambiguity may have led different participants to represent different concepts for a given noun (e.g., *bank* may have involved money for some participants, and rivers for others), the mean modality ratings per word reflect what a group of people tended to represent (see also Connell & Lynott, in press).

Table 2 shows a sample of nouns with their profile of ratings across modalities and modality exclusivity scores (i.e., a measure of the extent to which a particular concept is perceived through a single perceptual modality, calculated per word as the rating range divided by the sum, and extending from 0%, for completely multimodal, to 100%, for completely unimodal; see Lynott & Connell, 2009). Each noun was assigned a dominant modality (auditory, gustatory, haptic, olfactory, or visual) according to its strongest perceptual modality (i.e., the one that received the highest mean rating). Where ties existed for the strongest modality (four nouns out of 400), one tied modality was chosen at random as the dominant label. The complete norms may be downloaded as Supplemental Materials from the journal website.

Table 1 Mean ratings of perceptual strength (0–5) for 400 nouns across five modalities, with standard deviations, standard errors, and 95% confidence intervals per scale

Modality	M	SD	SE	95% CI
Auditory	2.15	1.09	0.05	0.11
Gustatory	0.53	0.79	0.04	0.08
Haptic	1.87	1.12	0.06	0.11
Olfactory	0.83	0.85	0.04	0.08
Visual	3.54	0.82	0.04	0.08

Relationship between modalities Table 3 shows the distribution of nouns over the five dominant modalities, with their mean ratings and modality exclusivity scores. The clustering in Fig. 1 illustrates how noun concepts overlap in perceptual experience, where ratings on the five modalities have been reduced to two factors using principal components analysis (the covariance matrix, with varimax rotation and Kaiser normalization, explained 70.5% of the original variance) and plotted by dominant modality. The vast majority of the noun concepts in our randomly selected sample were visually dominant, although the moderate exclusivity score indicates that many of these words also had high perceptual strength in other modalities, and should therefore be characterized as bimodal (e.g., *chair* was rated 4.65 for visual and 4.24 for haptic, with negligible presence on the other modalities) or multimodal (e.g., *baby* was rated as 4.88 visual, 4.24 auditory, 3.65 haptic, and 3.12 olfactory). Auditory-dominant nouns had the highest exclusivity scores, indicating that sound-related experience was the most perceptually distinct among the modalities, whereas the tiny number of olfactory-dominant nouns had the lowest exclusivity and the least distinct perceptual experience. Noun concepts that could be both tasted and smelled (e.g., *food*, *honey*) tended to be stronger in taste, and therefore emerged as gustatory-dominant nouns. As a result, the two olfactory-dominant words (e.g., *breath*, *air*) were those that could not be tasted, and they actually have lower olfactory strength than foodstuffs that were categorized as gustatory-dominant.

[1] Note that this instruction line was syntactically structured to accommodate the presentation of noun concepts, whereas Lynott and Connell's (2009) instruction line was originally structured for adjective concepts, in the form "To what extent do you experience something being *WORD*" (with the *WORD* slot being filled with the adjective in question). This change was the only task difference between our adjective and noun norms.

Table 2 Sample of nouns from the norms for a range of modality exclusivity scores (%), including their ratings of perceptual strength (0–5) across five modalities

Noun	Auditory	Gustatory	Haptic	Olfactory	Visual	Modality Exclusivity	Dominant Modality
reflection	0.24	0.00	0.47	0.17	4.65	84.0%	Visual
question	4.71	0.00	0.12	0.00	2.70	62.5%	Auditory
pride	2.88	0.06	0.71	0.12	3.24	45.4%	Visual
blanket	0.35	0.17	4.24	1.65	4.00	39.0%	Haptic
harmony	4.41	0.82	1.41	0.88	2.94	34.3%	Auditory
honey	0.65	4.76	2.82	3.76	4.12	25.5%	Gustatory
breath	2.18	2.18	1.70	3.00	1.71	12.0%	Olfactory
item	2.75	2.69	4.06	2.93	4.06	8.3%	Haptic

Some systematic relationships emerged between the ratings in different modalities (see Table 4). The strongest positive correlations were between gustatory–olfactory ratings (i.e., foodstuffs are usually smelled and tasted) and between visual–haptic ratings (i.e., many things that can be touched can also be seen), following the pattern found for adjective concepts. Other positive, but weaker, relationships existed between haptic–gustatory, haptic–olfactory, and visual–olfactory experience, perhaps reflecting that foodstuffs are also touchable and visible. Auditory experience was distinct from perceptual experience in other modalities: Auditory ratings were negatively correlated with haptic ratings and had no appreciable relationship with any other modality. There was also no relationship between visual and gustatory experience.

Differences between noun and adjective norms The modality exclusivity scores for nouns in this study (M = 39.2%) were significantly lower than those previously reported in Lynott and Connell (2009) for adjectives (M = 46.1%), $t(821)$ = 6.65, $p < .0001$, indicating that noun concepts are more multimodal in nature than are adjective concepts.[2] The variance across concepts in each modality ranged from 0.79 to 1.12 for the present noun norms (Table 1), which is lower than the variance found previously for adjective norms (range 1.16–1.60).

Overall, most of the relationships between modalities followed Lynott and Connell's (2009) previous findings for adjectives. Smell and taste experience were strongly linked on both word sets, as were sight and touch, while sound-related experience was the most perceptually distinct, with no reliable positive correlation with any modality. However, many differences between word classes also emerged. While auditory experience of adjective concepts was negatively related to experience in all other modalities (rs ranging from − .238 to − .360), auditory experience of noun concepts retained a weakly negative correlation only with haptic experience (r = − .177) and lost any relationship with the other modalities (rs ranging from − .018 to .094). Our examination of individual words suggests that this pattern emerges from the increased multimodality of noun concepts relative to adjectives. Strongly auditory adjectives tend to isolate sound experience alone (e.g., *echoing*, *loud*, *shrill*): Auditory-dominant adjectives had a moderately high modality exclusivity score of 58.4%. In contrast, strongly auditory nouns frequently refer to things that can also be seen and touched and, in some cases, smelled or tasted (e.g., *baby*, *gun*, *sea*): The exclusivity score for auditory-dominant noun concepts is therefore much lower, at 44.1%, $t(108)$ = 5.29, $p < .0001$.

Other key differences center on smell and taste experience. Although olfaction was negatively related to both visual (r = −.360) and tactile ratings (r = −.233) when people considered adjectives, the relationships flipped to positive (rs = .325 and .434, respectively) when people considered nouns. Modality exclusivity scores could not be compared directly between word classes on the basis of olfactory dominance, because there were only two olfactory-dominant nouns in our set of 400. However,

Table 3 Numbers of nouns and exclusivity scores (as percentages) per dominant modality, with the mean ratings of perceptual strength (0–5) in each modality

	Dominant Modality				
Variable	Auditory	Gustatory	Haptic	Olfactory	Visual
Auditory rating	3.58	1.12	1.35	1.62	2.03
Gustatory rating	0.20	4.63	0.72	1.82	0.48
Haptic rating	1.00	2.46	4.14	1.91	1.87
Olfactory rating	0.38	3.38	1.20	2.77	0.82
Visual rating	2.71	3.45	3.43	1.53	3.67
Modality exclusivity	44.1%	24.6%	35.3%	14.6%	39.1%
N	42	6	14	2	336

[2] Since these are item-level norms, by-items comparisons are appropriate in order to take word-sampling variance into account (Clark, 1973). However, the same difference emerged when the mean modality exclusivities per participant were compared between the noun (47.9%) and adjective (54.2%) norms, $t(95)$ = 2.95, p = .004.

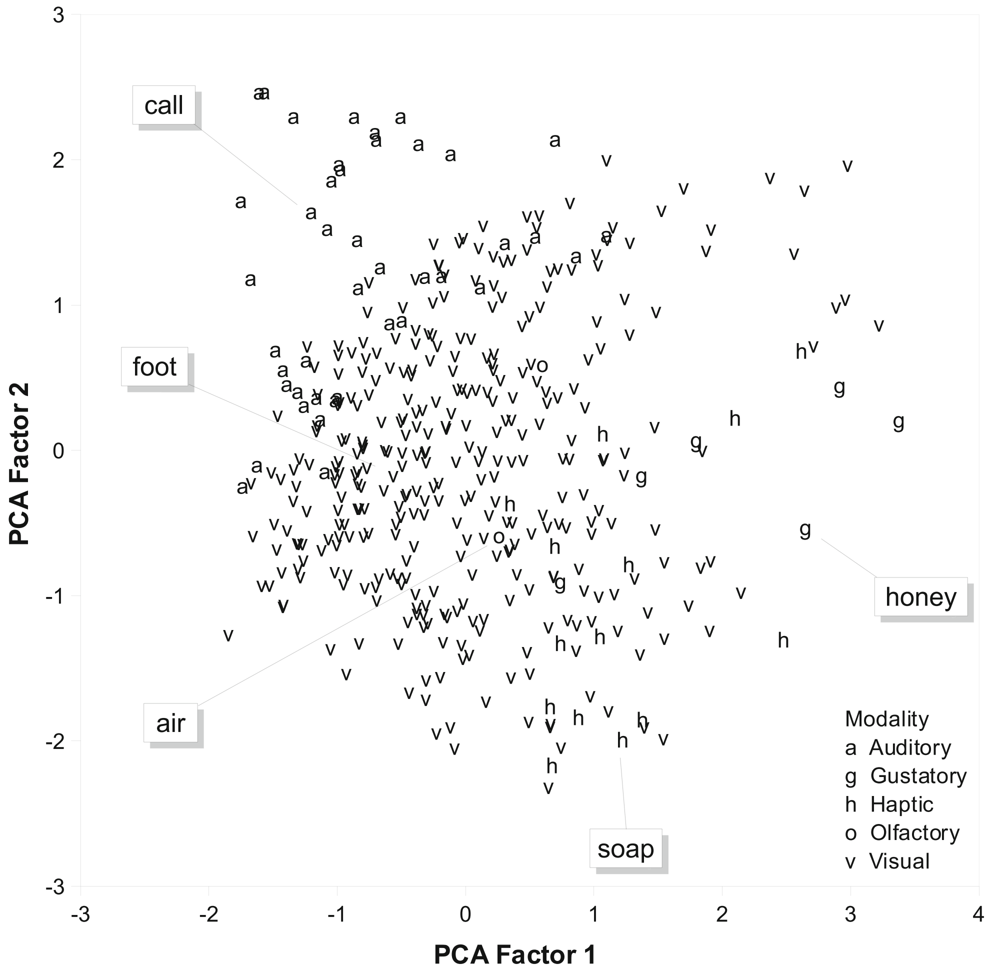

Fig. 1 Clustering of noun concepts, labeled by dominant modality, with perceptual strength on the five individual modalities reduced to two principal components analysis (PCA) factors

an examination of individual words with high olfactory strength (i.e., olfactory ratings greater than 3.0 out of 5) showed that, once more, this shift in intermodality relationships was likely due to olfactory adjectives having higher modality exclusivity (36.2%) than do olfactory nouns (22.3%), $t(90) = 4.85$, $p < .0001$. Since many strongly olfactory nouns refer to objects that can also be seen and touched (e.g., *honey*, *sauce*, *soap*), these concepts score highly on all three modalities. Such modality confluences were rare amongst adjective concepts, however, in which strongly olfactory words tended to isolate aspects of perceptual experience that were not visible or touchable (e.g., *pungent*, *fragrant*), with only occasional overlaps with modalities such as vision (e.g., *fishy*). The same trends can explain why gustation lost its negative relationship to visual experience between adjectives ($r = -.249$) and nouns ($r = .053$), while gaining a positive correlation with haptic experience (rs $= -.086$ and .287, respectively). Gustatory experience closely followed olfactory experience, with a few exceptions; some noun concepts that can be perceived by taste do not have corresponding olfactory strength (e.g., *treat*, *liquid*), while some olfactory items are not usually tasted (e.g., *paint*, *soap*). As with olfaction, modality exclusivity was higher for strongly gustatory adjectives (32.9%) than nouns (18.9%), $t(81) = 4.58$, $p < .0001$, suggesting that the multimodal nature of noun concepts shifted the relationship with other modalities.

Perceptual strength and lexical characteristics

Previous studies have suggested that the perceptual information of a particular object is related to the surface qualities of its label (e.g., Farmer et al., 2006; Gallace

Table 4 Correlation matrix between modalities for mean ratings of perceptual strength

Rated Modality	Auditory	Gustatory	Haptic	Olfactory	Visual
Auditory	–	−.018	−.177*	.094	.006
Gustatory		–	.287*	.663*	.053
Haptic			–	.434*	.543*
Olfactory				–	.325*
Visual					–

* $p < .001$ ($N = 400$)

et al., 2011; Köhler, 1929; Ramachandran & Hubbard, 2001; Thompson & Estes, 2011); if so, one may therefore expect to see relationships between modality-specific perceptual strength and other word-form properties. In the following study, we explored whether our ratings of perceptual strength in five perceptual modalities could predict the lexical characteristics of word length, distinctiveness in sound and spelling, and word frequency and diversity. Note that because the sound symbolism hypothesis concerns the relationship between form and meaning across all words in a language, it was important to ensure that the item sets were not confounded by recognized exceptions to the arbitrariness assumption (e.g., onomatopoeic words). No onomatopoeic words occur amongst the auditory-dominant nouns in our norms, meaning that the item set is generally a representative sample of words that would traditionally be considered to have arbitrary form.

Language is primarily a spoken medium of communication, even in literate societies (e.g., average exposure to speech in the Unites States has been estimated at 65,000 words per day: Bohn & Short, 2009). As such, most of our language use requires auditory attention because it is in the form of speech. Since directing attention to a particular perceptual modality makes it easier to represent conceptual information in that modality (e.g., Connell, Lynott, & Dreyer, 2012; van Dantzig etal., 2008), it follows that auditory strength in a concept's representation should facilitate using its label in language; indeed, auditory strength has been shown to facilitate word-naming times (Connell & Lynott, 2012). We therefore expected the connection between meaning and auditory attention in language use to extend to the sound symbolism hypothesis; specifically, we expected strength in the auditory modality to be most closely related, among any of the five modalities, to the lexical properties of words. Furthermore, because auditory experience is negatively related or unrelated to other perceptual experience (see Table 4 above; Lynott & Connell, 2009), we expected any effects of auditory strength to pull in the opposite direction from the other modalities. The precise role of the other perceptual modalities, however, was an open question.

Method

Materials Lexical variables for the 400 nouns in our norming study above were extracted from the E-Lexicon database (Balota et al., 2007), as follows.

Measures of word length:

- number of syllables (e.g., *picture* = 2)
- number of phonemes (e.g., *picture* = 5)
- number of morphemes (e.g., *picture* → pict-/-ure = 2)
- number of letters (e.g., *picture* = 7)

Measures of word-form distinctiveness (note that distinctiveness is inversely related to neighborhood size: small neighborhoods = highly distinct):

- phonological neighborhood size (i.e., number of words that can be generated by switching one phoneme; e.g., *laughter* → *dafter*, *rafter* = 2)
- orthographic neighborhood size (i.e., Coltheart's *N*: number of words that can be generated by switching one letter; e.g., *laughter* → *daughter* = 1)
- phonographic neighborhood size (i.e., number of words in the overlap between phonological and orthographic neighbors; e.g., *laughter* → [nothing] = 0)

Measures of word frequency:

- frequency count in Brysbaert and New's (2009) subtitle corpus, based on 51 million words from movie and television scripts (e.g., *fear* = 69.08 occurrences per million words)
- contextual diversity (i.e., the variety of different contexts in which a word appears), expressed as a percentage of scripts in Brysbaert and New's (2009) subtitle corpus (e.g., *fear* = 22.79% of contexts)

Design and analysis The lexical variables above acted as dependent variables in separate stepwise regressions (bidirectional selection: inclusion criterion $p < .05$, exclusion criterion $p > .1$), with the perceptual strength ratings in five modalities (auditory, gustatory, haptic, olfactory, and visual) as competing predictors. Distinctiveness and frequency variables were log-transformed prior to the analysis to correct for skewed distributions of the residuals (i.e., skewness > 1.2). The residuals of all analyzed dependent variables had a skewness of < 1. Table 5 shows the correlation matrix between dependent variables. The relationships between categories of lexical characteristics followed those usually found in the literature: Word length is negatively correlated with both word frequency (i.e., Zipf's Law that short words are more common) and neighborhood size (i.e., short words have a larger number of close orthographic and phonological neighbors: Coltheart, Davelaar, Jonasson, & Besner, 1977), while neighborhood size and frequency are positively correlated (i.e., common words have more close neighbors than do rare words: Landauer & Streeter, 1973).

Results and discussion

Overall, perceptual strength could significantly predict all lexical variables. Table 6 shows the coefficients of both included and excluded modality predictors in each analysis. Models of word length all followed much the same pattern:

Table 5 Correlation matrix between dependent variables in regression analyses of lexical characteristics, with means and standard deviations

Variable	Correlation Variables[a]										
	S	P	M	L	PN	ON	PGN	WF	CD	Mean	SD
Length measures											
Number of syllables (S)	–	.867	.724	.864	−.752	−.702	−.611	−.443	−.439	1.85	0.96
Number of phonemes (P)		–	.712	.921	−.819	−.728	−.611	−.461	−.457	4.99	1.98
Number of morphemes (M)			–	.764	−.571	−.528	−.432	−.439	−.435	1.38	0.63
Number of letters (L)				–	−.773	−.766	−.648	−.458	−.443	6.04	2.19
Distinctiveness measures											
Log phonological neighborhood size (PN)					–	.854	.806	.460	.445	0.76	0.60
Log orthographic neighborhood size (ON)						–	.897	.415	.391	0.53	0.47
Log phonographic neighborhood size (PGN)							–	.367	.343	0.36	0.42
Frequency measures											
Log word frequency (WF)								–	.980	3.20	0.65
Log contextual diversity (CD)									–	2.95	0.51

[a] All correlations are significant at $p < .001$ ($N = 400$)

Length increased with stronger auditory (and, to some extent, gustatory) experience, but decreased with stronger haptic experience. In other words, things that we can touch tend to attract short names (*cup*, *bone*), while things that we can see or smell are equally labeled with long and short words (*fog*, *reflection*), and things that we can hear or taste tend to attract longer labels (*harmony*, *laughter*). These effects are not large, but perceptual strength could reliably explain 6%–9% of the variance across measures: number of syllables [adjusted $R^2 = .092$; $F(3, 396) = 14.49$, $p < .0001$], phonemes [$R^2 = .089$; $F(2, 397) = 20.54$, $p < .0001$], morphemes [$R^2 = .057$; $F(2, 397) = 12.97$, $p < .0001$], and letters [$R^2 = .081$; $F(2, 397) = 18.64$, $p < .0001$]. In short, whether defined by spoken or written form, long words tend to denote sounds and other intangible things.

Models of word distinctiveness also followed a consistent pattern: Neighborhood size increased with stronger haptic experience, and decreased with stronger auditory (and, to some extent, gustatory) experience. Since highly distinctive words are usually relatively long (e.g., *admission*,

Table 6 Standardized coefficients of each modality predictor in stepwise regressions on each lexical dependent variable, with coefficients of excluded predictors shown in parentheses

Variable	Auditory	Gustatory	Haptic	Olfactory	Visual
Length measures					
Number of syllables	+0.16**	+0.11*	−0.25***	(+0.05)	(+0.10)†
Number of phonemes	+0.15**	(+0.08)	−0.24***	(+0.06)	(+0.09)
Number of morphemes	+0.13**	(+0.09)†	−0.19***	(+0.06)	(+0.09)
Number of letters	+0.08**	(+0.09)†	−0.32***	(+0.06)	(+0.11)†
Distinctiveness measures					
Log phonological neighborhood size	−0.18***	(−0.09)†	+0.26***	(−0.06)	(−0.07)
Log orthographic neighborhood size	−0.19***	(−0.09)†	+0.22***	(−0.04)	(−0.07)
Log phonographic neighborhood size	−0.15**	−0.14**	+0.22***	(−0.07)	(−0.11)†
Frequency measures					
Log frequency count	+0.13*	(−0.05)	+0.15**	(−0.01)	(−0.05)
Log contextual diversity	+0.11*	(−0.04)	+0.16**	(−0.02)	(−0.07)
Principal components analysis					
Component 1 (length)	+0.15**	(+0.06)	−0.18***	(+0.04)	(+0.07)
Component 2 (distinctiveness)	−0.17***	(−0.10)†	+0.16**	(−0.08)	(−0.06)
Component 3 (frequency)	+0.17***	(+0.01)	(+0.10)†	(+0.05)	(+0.03)

*** $p < .001$; ** $p < .01$; * $p < .05$; † $p < .1$

emergency; see Table 5), the findings closely reflect those of the word length measures. Haptic strength attracts common word forms with many neighbors (e.g., *bone* has 11–50 neighbors, depending on the measure), while auditory strength pulls in the opposite direction, by attracting unusual word forms with few neighbors (e.g., *music* has 0–3 neighbors). Perceptual experience collectively explained approximately 8%–11% of the variance across distinctiveness measures: size of phonological neighborhood [$R^2 = .111$; $F(2, 397) = 8.36$, $p < .0001$], orthographic neighborhood [$R^2 = .092$; $F(2, 397) = 21.27$, $p < .0001$], and phonographic neighborhood [$R^2 = .075$; $F(3, 396) = 11.80$, $p < .0001$]. Distinctive word forms (i.e., those with small neighborhoods, whether defined by sound or spelling) tend to denote sounds and other intangible things.

Finally, models of word frequency showed a slightly different pattern of results from either length or distinctiveness: Frequency of occurrence increased with stronger auditory and stronger haptic experience. In other words, both auditory and haptic strengths show the same direction of relationship for the first time: Words referring to things that we can hear or touch tend to appear frequently and in a large variety of contexts, whereas words denoting vision, smell, and taste show no consistent pattern. Overall, perceptual strength explained less than 3% of variance for both count frequency [$R^2 = .028$; $F(2, 397) = 6.69$, $p = .001$] and contextual diversity [$R^2 = .027$; $F(2, 397) = 6.51$, $p = .002$]. Common words—whether measured in terms of counts or contexts—tend to denote perceptible entities that we can touch or hear.

Principal components analysis Since length, distinctiveness, and frequency are intercorrelated (i.e., long words tend to be lower in frequency and more distinct in sound/spelling; see Table 5), regressing each variable separately means that the perceptual effects on each category of lexical characteristic cannot be disentangled. We therefore entered all nine lexical variables into a principal components analysis (PCA; correlation matrix, unrestricted factors) in order to reduce the total dependent data set down to a minimum number of meaningful dimensions. Scree analysis showed that three components explained 91.3% of the original variance, while the other components explained less than 3.5% each. We consequently reran a PCA to extract only three components and used varimax rotation with Kaiser normalization to render the components orthogonal (i.e., uncorrelated). The rotation converged in five iterations, and these three rotated components respectively explained 35.6%, 32.4%, and 23.4% (total 91.3%) of the overall variance. When correlated against the original lexical variables, loadings on these three orthogonal components corresponded closely to the three categories of length, distinctiveness, and frequency (see Table 7).

We then ran stepwise regressions, as before, on the loadings of each orthogonal PCA component. The results closely followed the previous analysis of separate variables, as is shown by the coefficients at the bottom of Table 6. Component 1 (corresponding to word length) increased with auditory strength and decreased with haptic strength [adjusted $R^2 = .059$; $F(2, 397) = 13.60$, $p < .0001$]. The inverse was true for Component 2 (corresponding to distinctiveness), which was negatively predicted by auditory strength and positively by haptic strength [$R^2 = .057$; $F(2, 397) = 13.14$, $p < .0001$]. Finally, Component 3 (corresponding to frequency) was positively predicted by auditory strength [$R^2 = .027$; $F(1, 398) = 11.87$, $p < .001$]; haptic strength, although a significant predictor of separate frequency variables, had only a marginally positive effect. Even when the lexical characteristics of word length, distinctiveness, and frequency are separated into uncorrelated components, they are still significantly predicted by the perceptual strength of the referent concept. In short, distinctive perceptual experience leads to distinctive labels. Sound experience is quite perceptually distinct (i.e., auditory strength is either negatively related or unrelated to all other modalities), and so, too, are the words that we use to describe such experience; auditory experience tends to attract longer labels with distinctive pronunciations and spellings. Concepts that are strongly auditory tend to be labeled with words that are long, distinctive, and relatively high in frequency, whereas concepts that relate strongly to the sense of touch tend to be labeled with short words that are common in form.

General discussion

We have presented modality exclusivity norms for 400 randomly selected noun concepts as an extension of

Table 7 Structure matrix for orthogonal principal components of lexical variables

Lexical Variable	Component 1	Component 2	Component 3
Number of syllables	**.798**	−.435	−.195
Number of phonemes	**.794**	−.471	−.209
Number of morphemes	**.864**	−.142	−.239
Number of letters	**.808**	−.477	−.196
Log phonological neighborhood size	−.488	**.768**	.224
Log orthographic neighborhood size	−.386	**.868**	.174
Log phonographic neighborhood size	−.233	**.921**	.150
Log frequency count	−.218	.188	**.952**
Log contextual diversity	−.221	.162	**.956**

Correlation coefficients greater than .70, meaning that at least half of the variance in a variable is explained by the component, are displayed in bold previous norms that had focused on adjective concepts (Lynott & Connell, 2009; van Dantzig et al., 2011), and found that the conceptual content of nouns is more multimodal than that of adjectives. When we examined the lexical characteristics of these nouns, we found evidence of a systematic relationship between strength of perceptual experience in the referent concept and surface word form: Words that refer to sounds and other intangible entities tend to be long, frequent, and unusual in their construction, while words that refer to touch tend to be short, frequent, and common in form. In other words, modality-specific norms are not just useful for exploring the nature of grounded concepts, but also the nature of form–meaning relationships.

While some previous work has reported how lexical characteristics differ between abstract and concrete concepts, the present findings exhibit quite different trends. To begin with, the precise relationship between concreteness and perceptual information is a complex and controversial one, with various theories disagreeing as to whether perceptual information is central to concrete concepts (e.g., Paivio's, 1971, dual-coding theory) or is completely irrelevant (e.g., Schwanenflugel & Shoben's, 1983, context availability theory). In related work (Connell & Lynott, in press), we show that concreteness and imageability ratings do not reflect the perceptual basis of concepts well, so the fact that lexical characteristics exhibit differing relationships with concreteness and measures of perceptual strength is perhaps unsurprising. For example, concrete words are often described as shorter than abstract words (e.g., Spreen & Schultz, 1966). However, we find that the relationship between word length and perceptual strength is far more complex: The strength of haptic experience behaves like concreteness, in that things that we can touch tend to attract short names (*cup*, *bone*), while things that we can see or smell are equally labeled with long and short words (*fog*, *reflection*), and things that we can hear or taste tend to attract longer labels (*harmony*, *laughter*). Similarly, concrete words have previously been shown to be less distinctive than abstract words (i.e., to have larger orthographic neighborhoods: Samson & Pillon, 2004), but we found that auditory strength pulls in the opposite direction, by attracting unusual word forms with few neighbors (e.g., *music* has 0–3 neighbors), while only haptic strength behaves like concreteness in attracting common word forms with many neighbors (e.g., *bone* has 11–50 neighbors, depending on the measure). Several studies have reported a general trend for concrete words to be more frequent than abstract words (e.g., Spreen & Schultz, 1966), but, counterintuitively, contextual diversity shows the opposite trend: Concrete words appear in *fewer* contexts than abstract words (e.g., Galbraith & Underwood, 1973; Schwanenflugel & Shoben, 1983), a relationship that has informed theories of conceptual structure (Barsalou & Wiemer-Hastings, 2005; Schwanenflugel & Shoben, 1983). Our findings are at least consistent in finding the same direction of effects: Words referring to things that we can hear or touch tend to appear with higher frequency in a large variety of contexts (although words denoting vision, smell, and taste show no consistent pattern).

The present findings are consistent with the sound symbolism hypothesis, because the lexical characteristics of word forms are systematically related to the perceptual basis of the referent concepts. While previous work has reported a relationship between the sound of a word and its lexical category (nouns vs. verbs: Farmer et al., 2006), our findings suggest that more fine-grained distinctions may be possible using modality profiles of perceptual strength. The mere presence of statistical regularities between sound and meaning may facilitate word learning (Imai et al., 2008; Nygaard et al., 2009), and certain body–form correspondences (e.g., rounded lips for round shapes) may even have helped shape how language evolved (Ramachandran & Hubbard, 2001). The findings that we report here go a step farther in linking word form to the perceptual profile of conceptual content. In the vocabulary of a language, some words will always have to be longer and more unusual than others, because short and simple word forms eventually run out (i.e., there are only a finite number of distinctive monosyllabic words). But both length and distinctiveness come at the cost of making words more difficult to remember (Baddeley, Thomson, & Buchanan, 1975; Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002) and harder to learn as object labels (Storkel, Armbruster, & Hogan, 2006). However, since directing attention to a particular perceptual modality makes it easier to represent conceptual information in that modality (e.g., Connell et al., 2012; van Dantzig et al., 2008), it is possible that sound experience (which directs attention to the auditory modality) helps to counter some of these costs. If one must learn or retrieve a long and unusual word, it may be easier to do so for strongly auditory concepts, because the relevant system for processing the sound of words is already attentionally primed by speech. Over time, long and distinctive labels become associated more successfully with auditory concepts than with concepts relating to other perceptual modalities. Using a distinctive label for auditory concepts may minimize the chance of mishearing the label, thus helping speakers in a dialogue to establish referential identity when one cannot visually disambiguate the correct referent by looking or pointing (Clark & Brennan, 1991).

In summary, we have presented a set of modality-specific norms for a representative sample of noun concepts, and we observed both consistent and contrasting patterns for ratings of noun and adjective concepts. As with adjectives, noun concepts tended to show high visual dominance, with auditory-dominant concepts also having the highest modality exclusivity scores for both adjectives and nouns.

However, noun concepts tended to exhibit lower modality exclusivity than did adjectives, reflecting the greater multimodal perceptual experience of noun concepts, which tend to subsume several adjectival property concepts (e.g., *baby* shows perceptual strength on all modalities except gustatory, as it subsumes auditory *loud*, haptic *soft*, olfactory *stinky*, visual *cute*, etc.). Finally, we demonstrated the utility of these norms in their contribution to sound symbolism, in that the perceptual experience of referent concepts was shown to be related to the lexical properties of their labels. As these norms reflect the extent to which modality-specific experience varies across concepts, we hope that they will prove a useful tool for researchers working in the areas concerned with psycholinguistics, language development and evolution, mental representation, and synthetic embodiment.

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